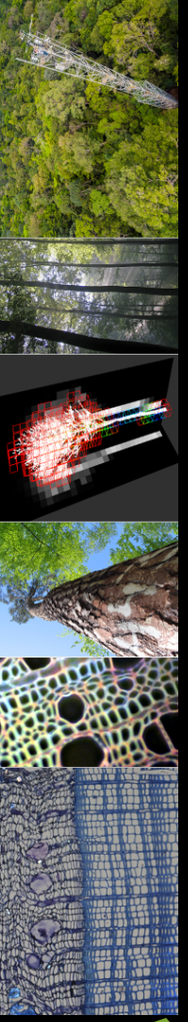
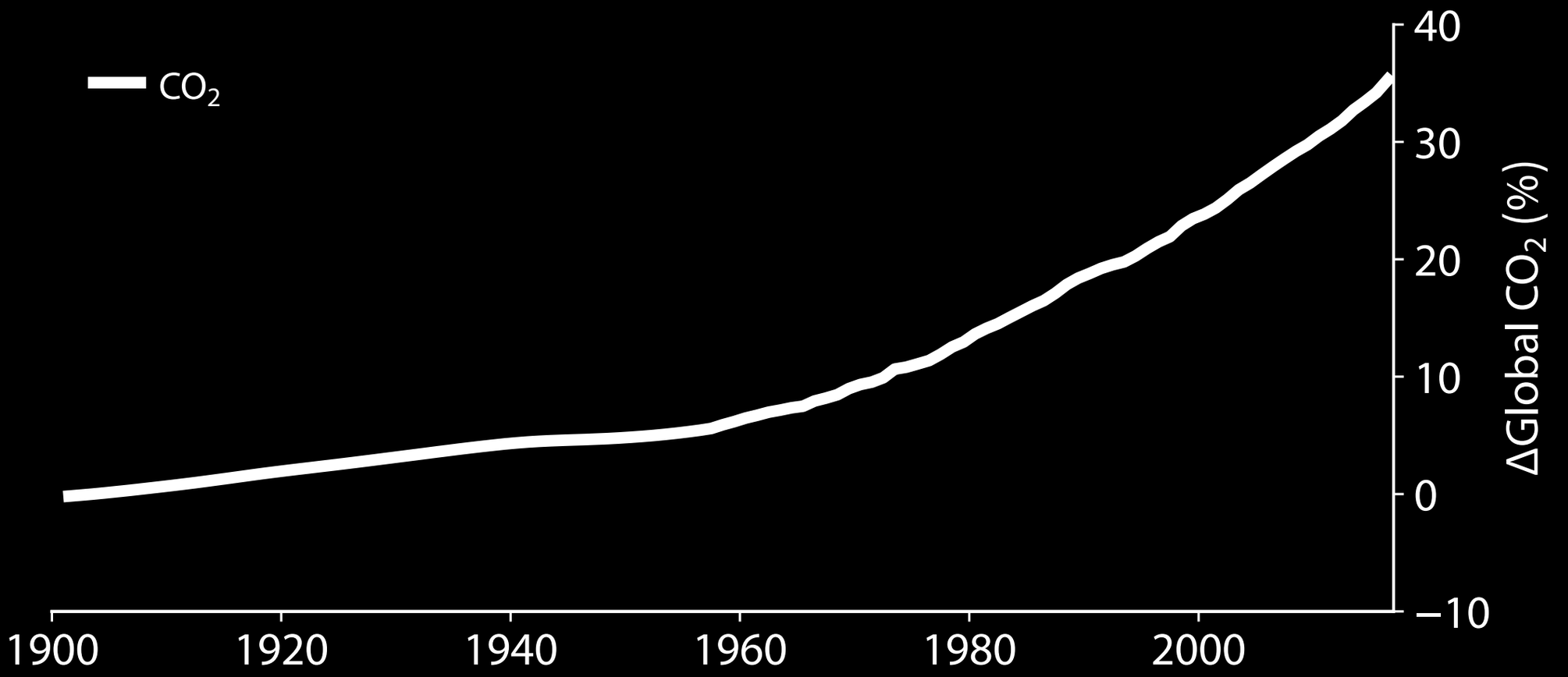
Higher global gross primary productivity under future climate with more advanced representations of photosynthesis

Jürgen Knauer[1], Matthias Cuntz[2], Benjamin Smith[1], Josep G. Canadell[3], Belinda Medlyn[1], Alison C Bennet[4], Silvia Caldararu[5], and Vanessa Haverd[3]

[1]Hawkesbury Institute for the Environment, Western Sydney University, Penrith, NSW, Australia
[2]Université de Lorraine, AgroParisTech, INRAE, UMR Silva, Nancy, France
[3]CSIRO Environment, Canberra, ACT, Australia
[4]School of Ecosystem and Forest Science, University of Melbourne, Richmond, VIC, Australia
[5]Botany, School of Natural Sciences, Trinity College Dublin, Dublin, Ireland

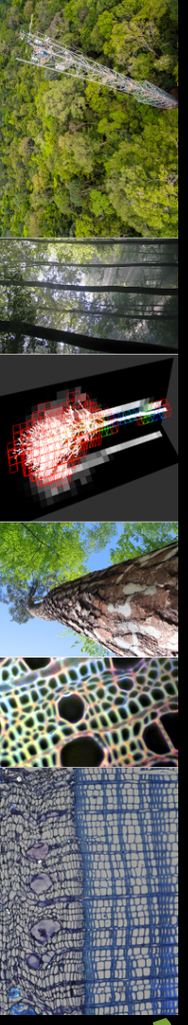


30% increase in [CO_2] during the last century

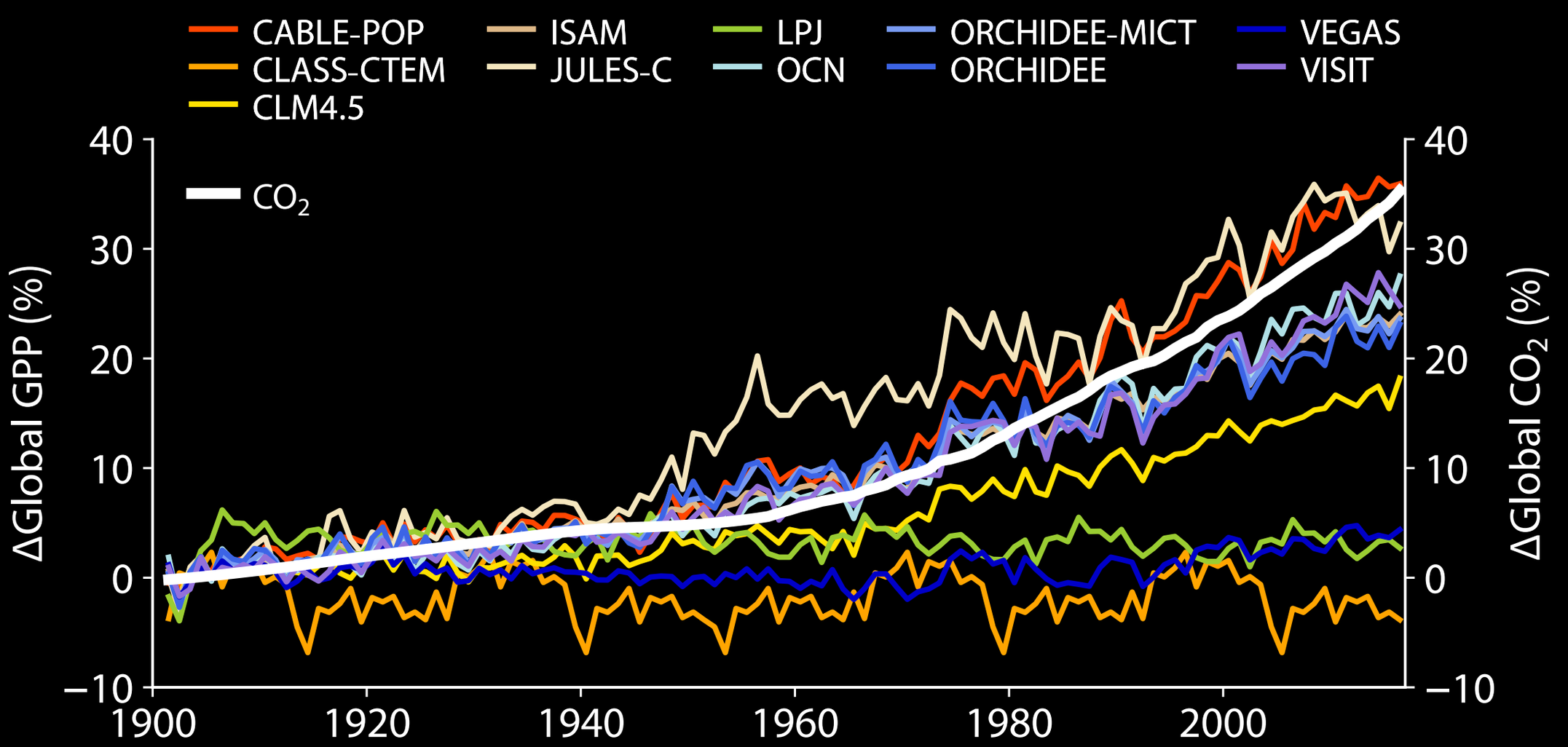


(Haverd *et al.* GCB 2020)

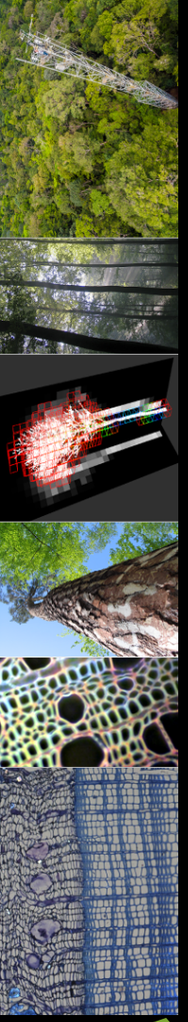
Large diversity of productivity increase in current land surface models during the last century



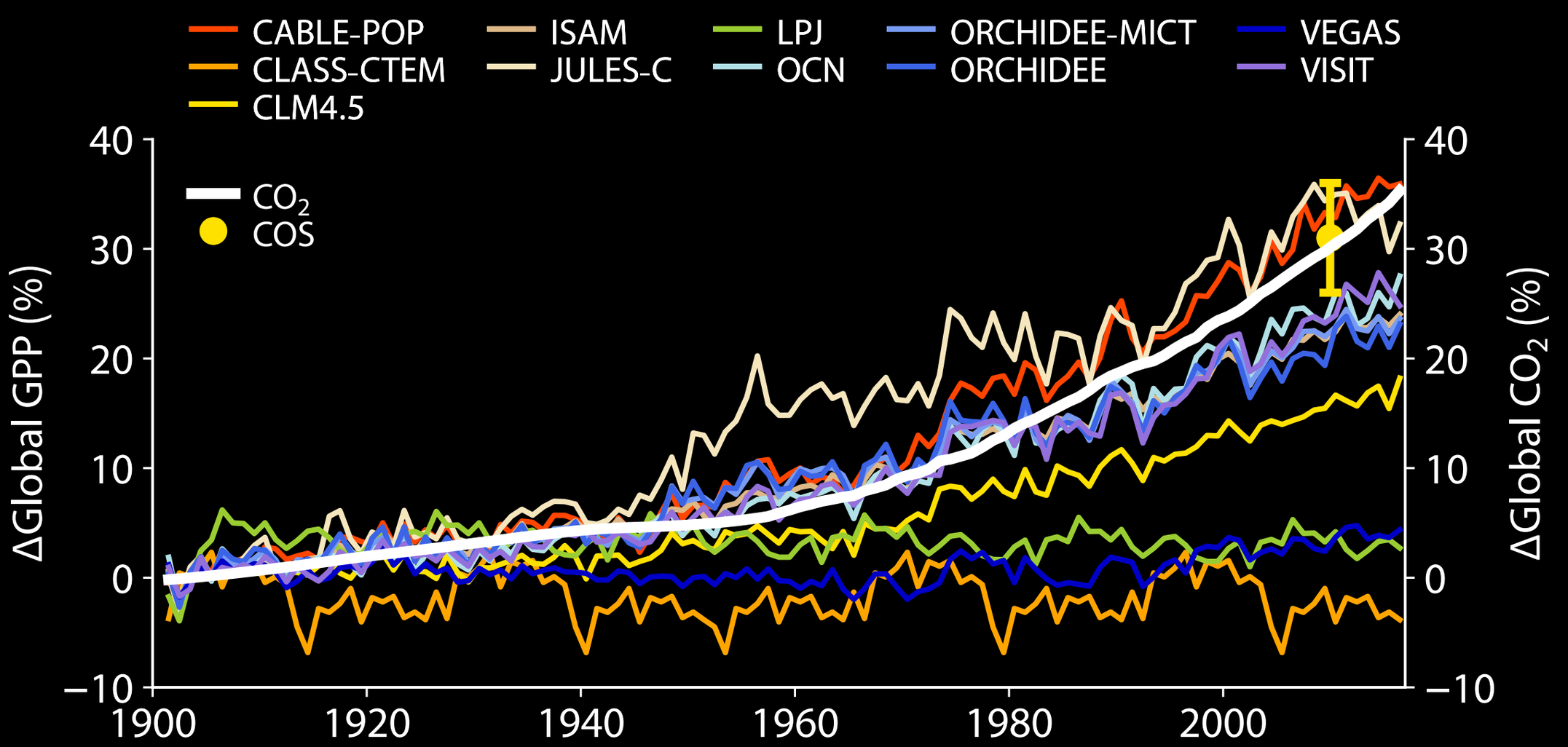
UMR Silva



(Haverd *et al.* GCB 2020)

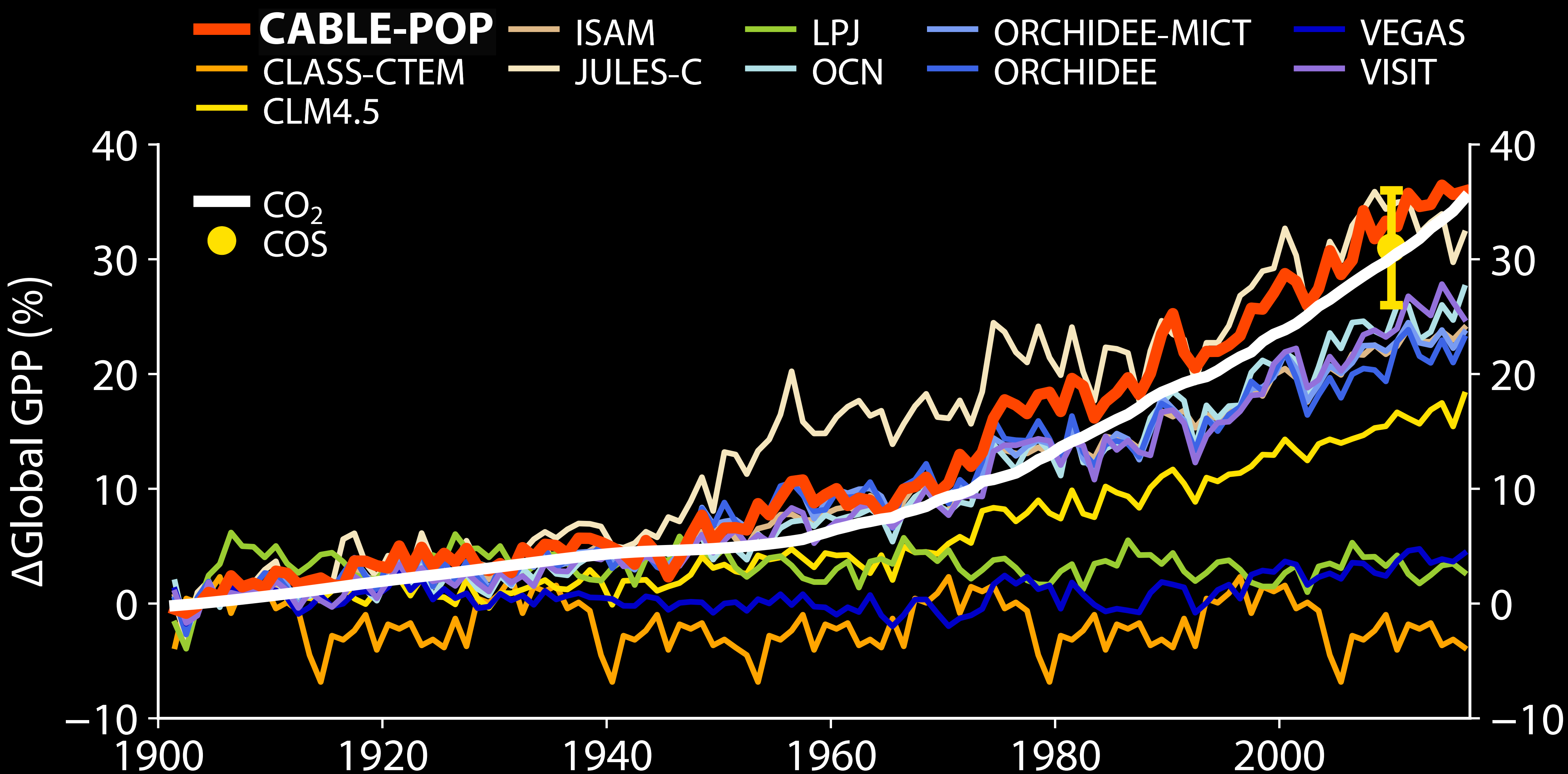


Large diversity of productivity increase in current land surface models during the last century



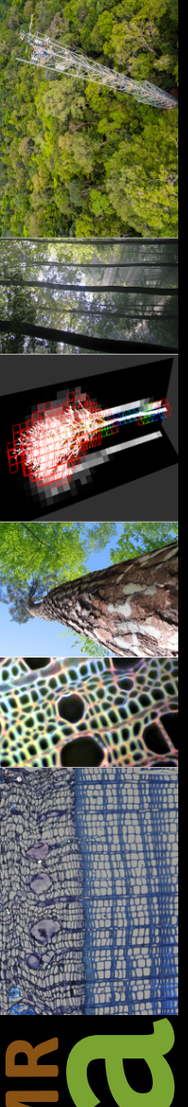
(Haverd *et al.* GCB 2020)

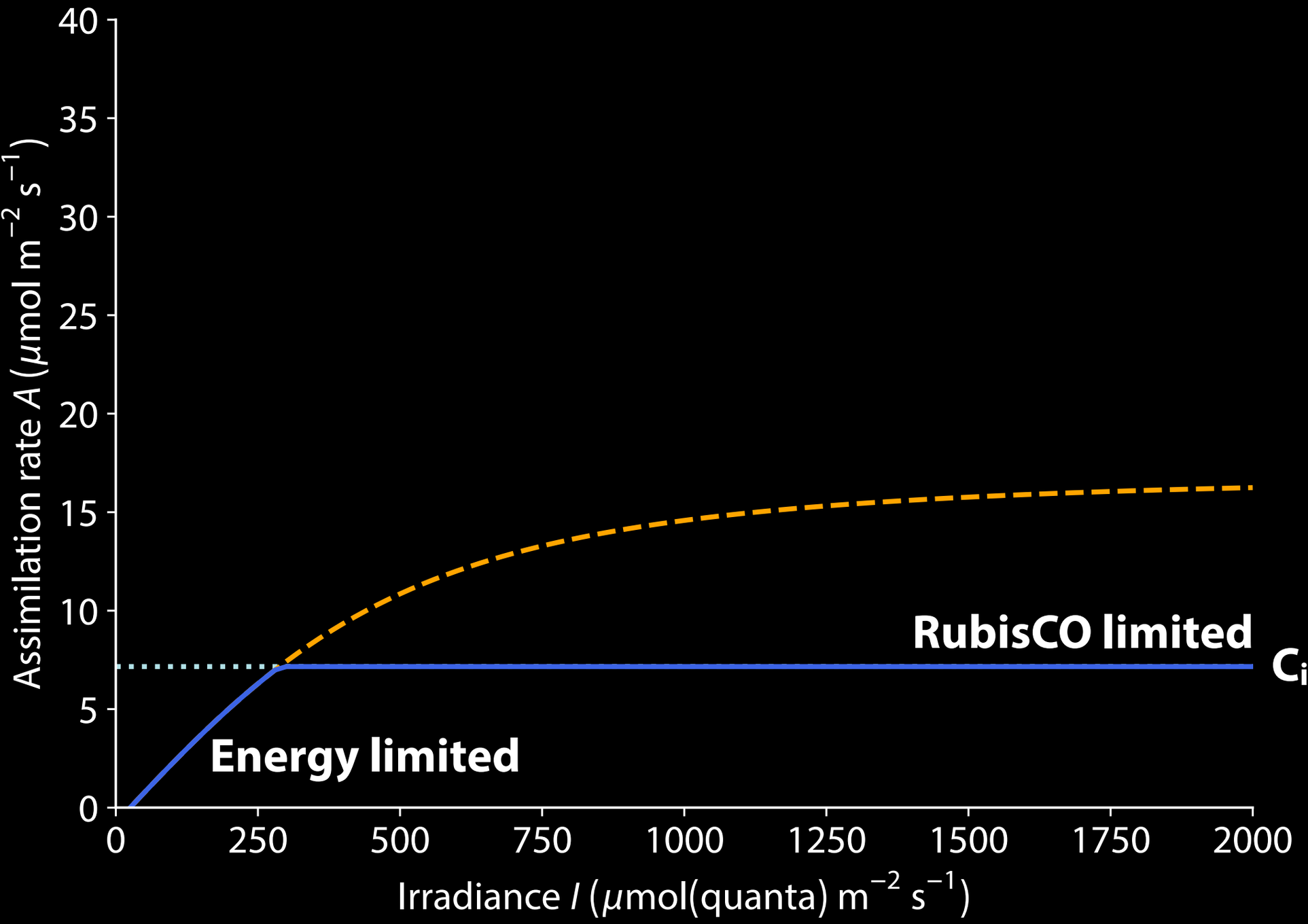
Large diversity of productivity increase in current land surface models during the last century



(Haverd *et al.* GCB 2020)

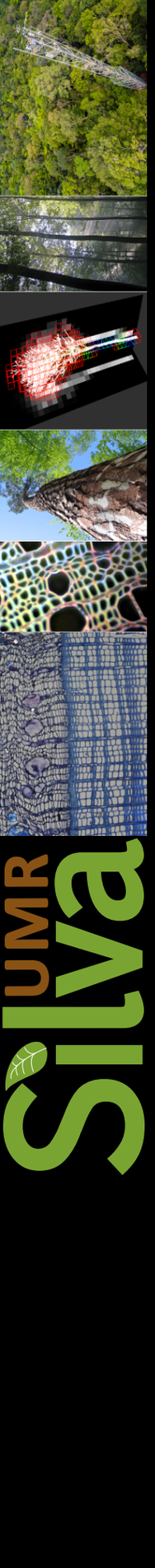
Limitations of photosynthesis

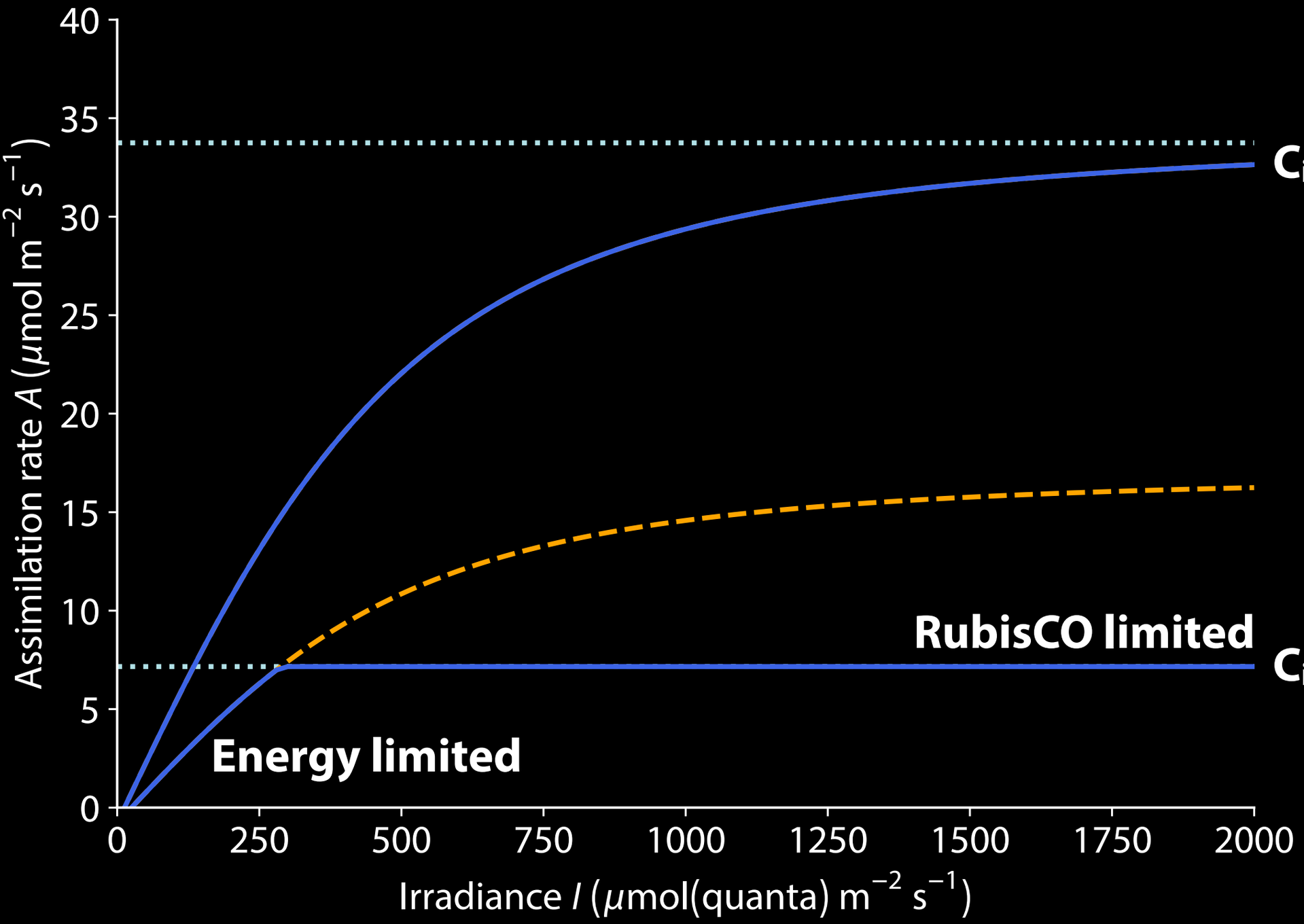




(von Caemmerer 2000)

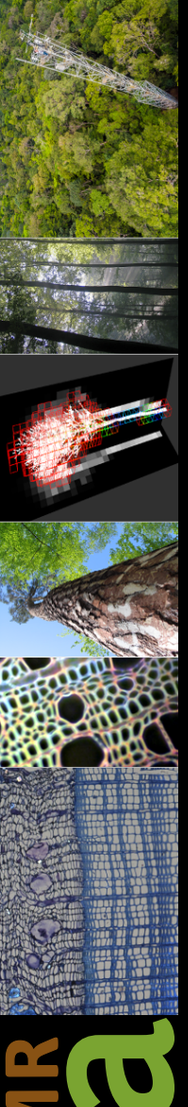
Limitations of photosynthesis

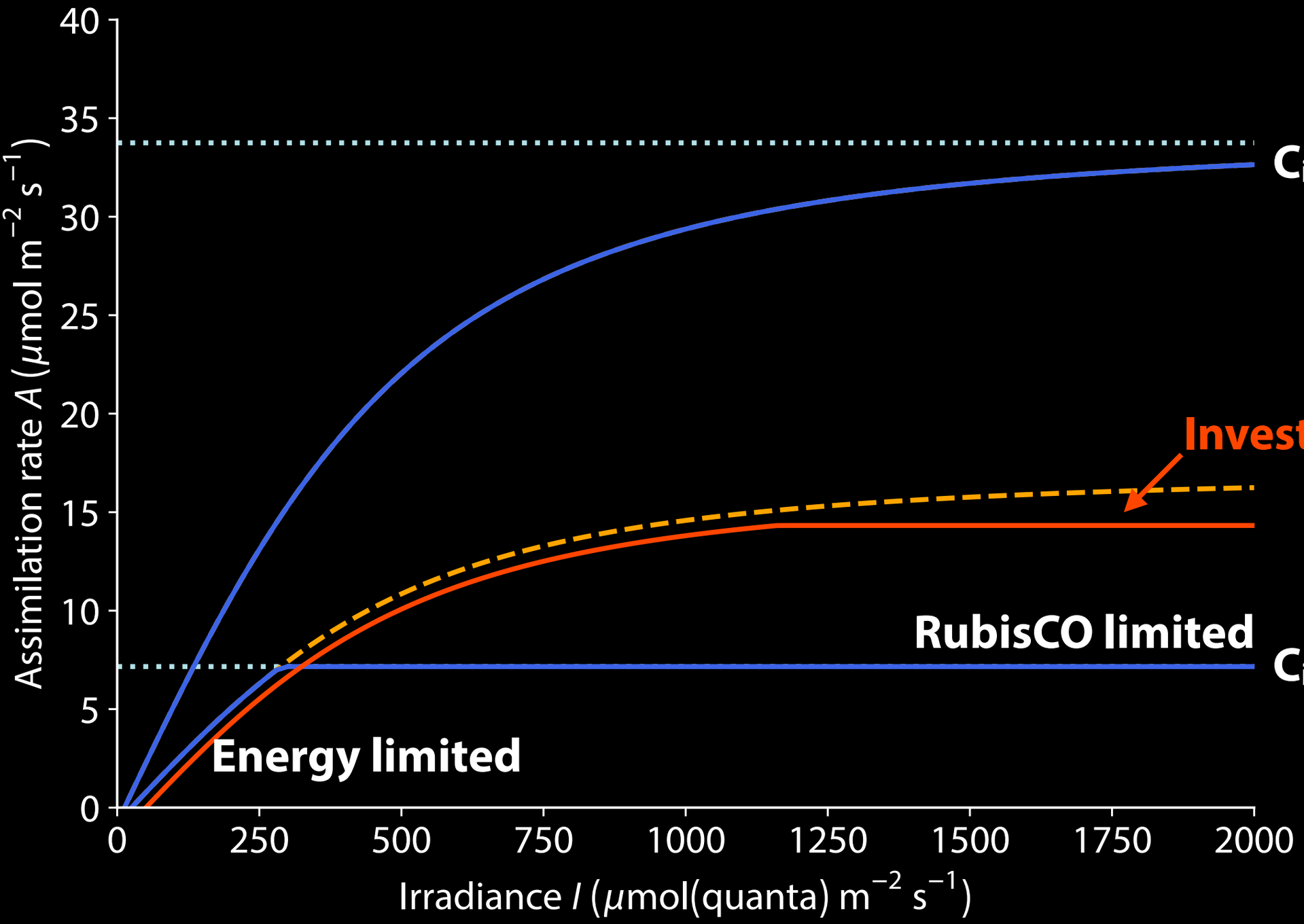




(von Caemmerer 2000)

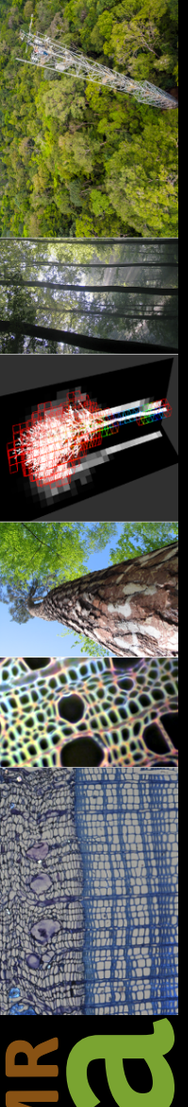
Limitations of photosynthesis

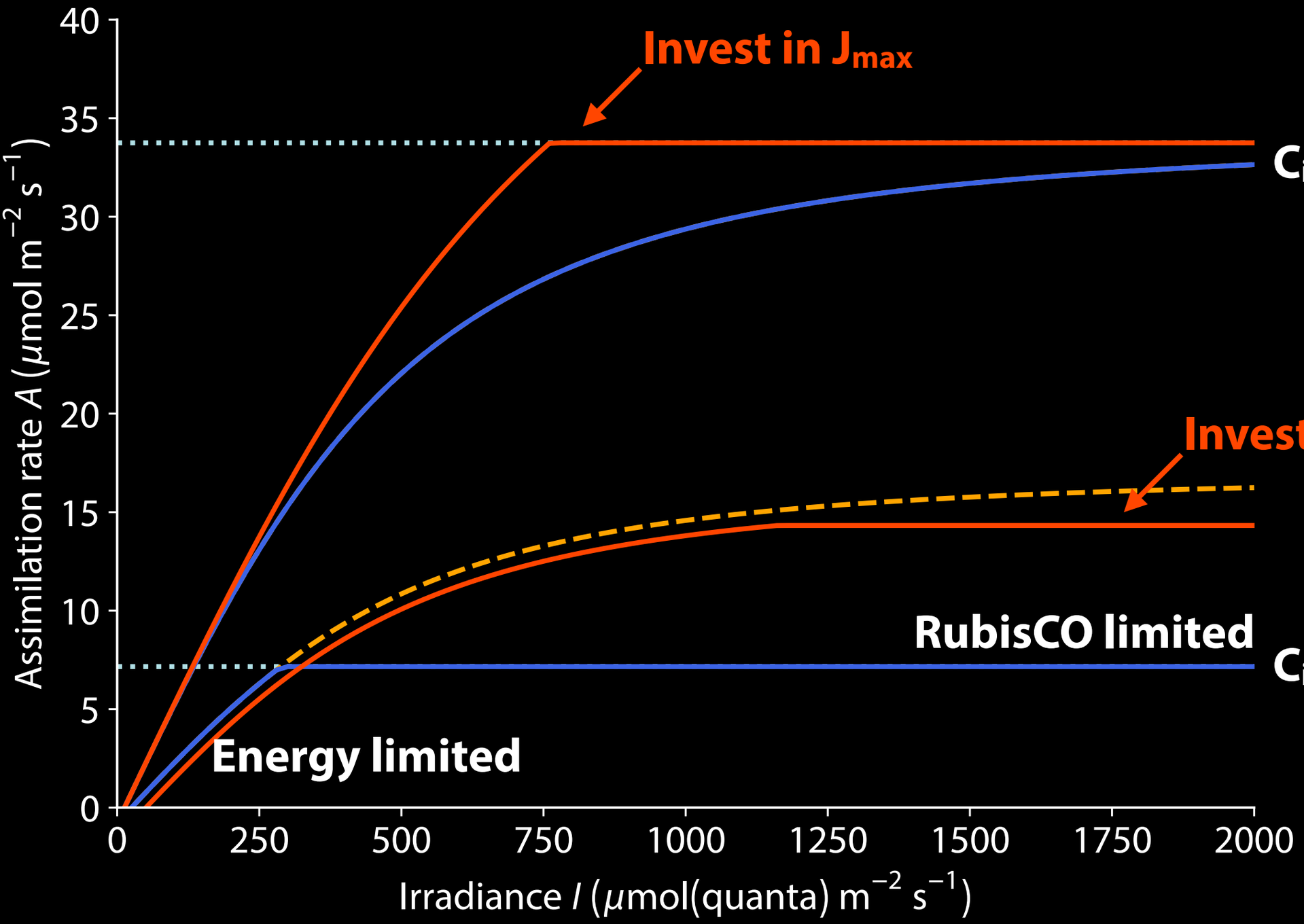




(von Caemmerer 2000)

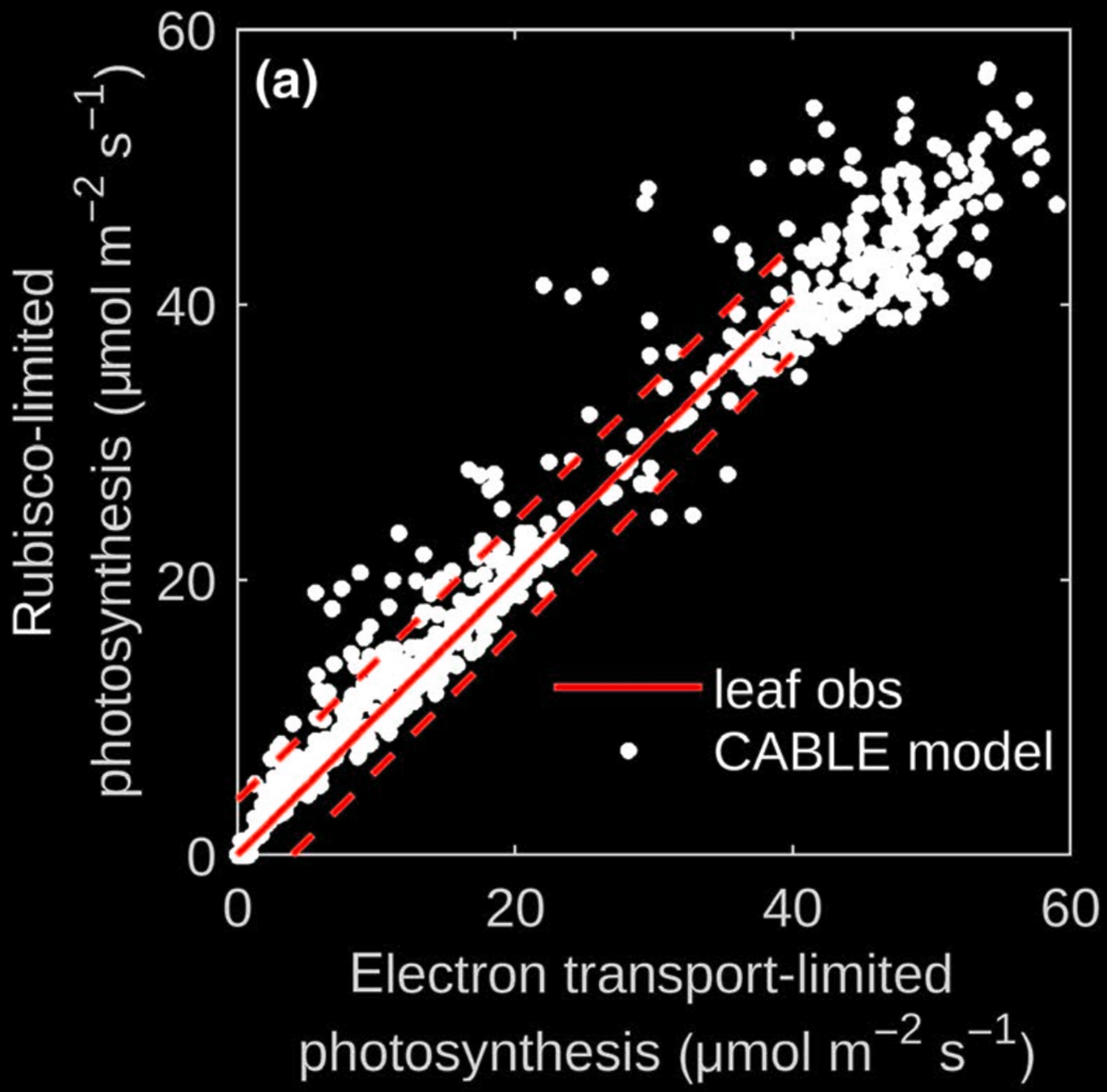
Limitations of photosynthesis





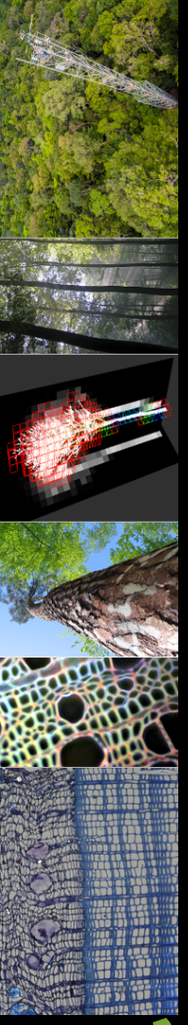
(von Caemmerer 2000)

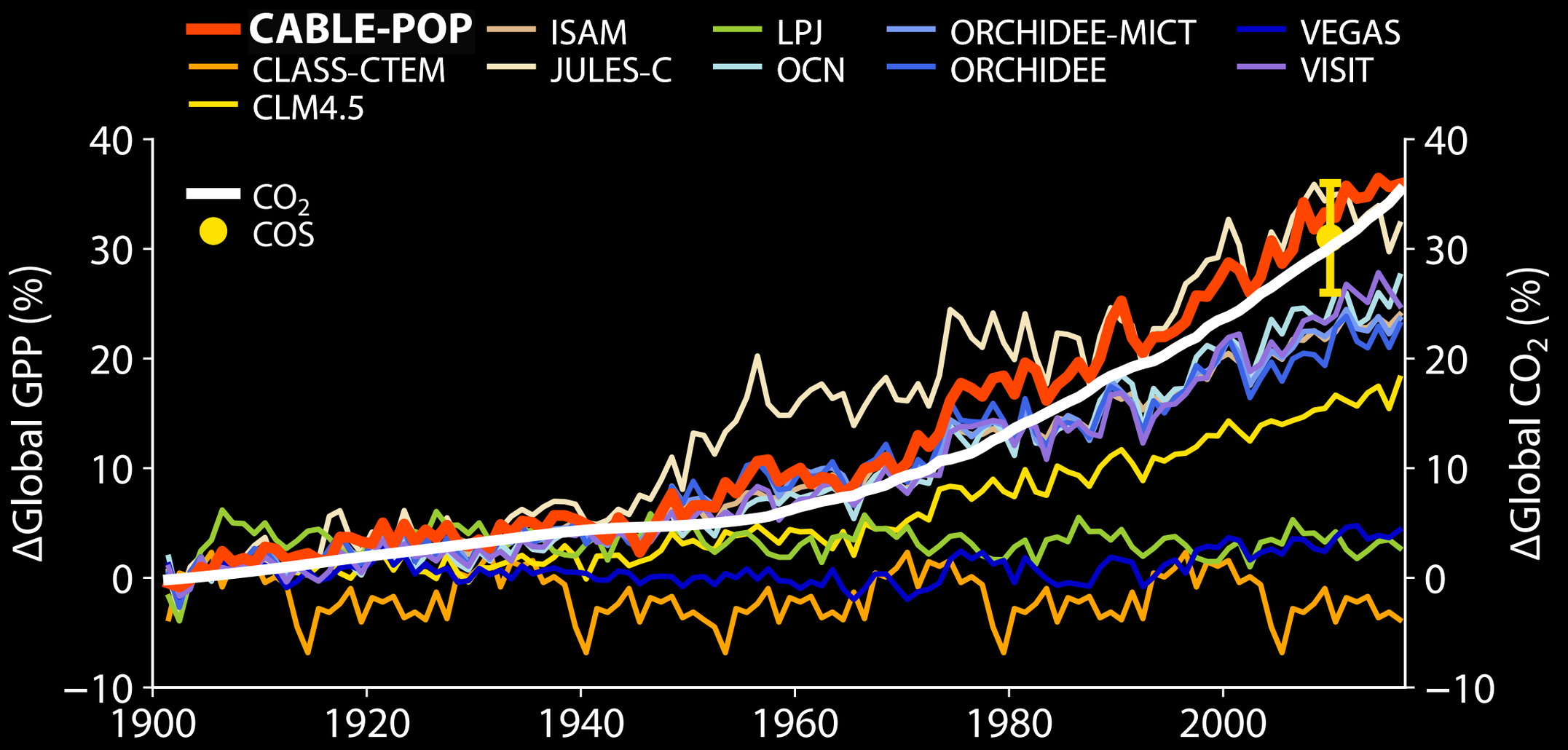
Optimising leaf nitrogen use leads to similar contributions of the different limitations of photosynthesis = coordination hypothesis (optim)



(Haverd *et al.* GCB 2020)

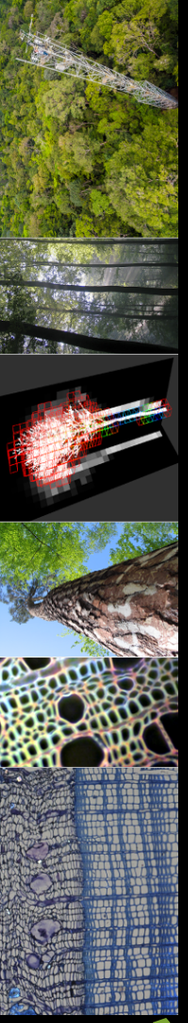
Large diversity of productivity increase in current land surface models during the last century

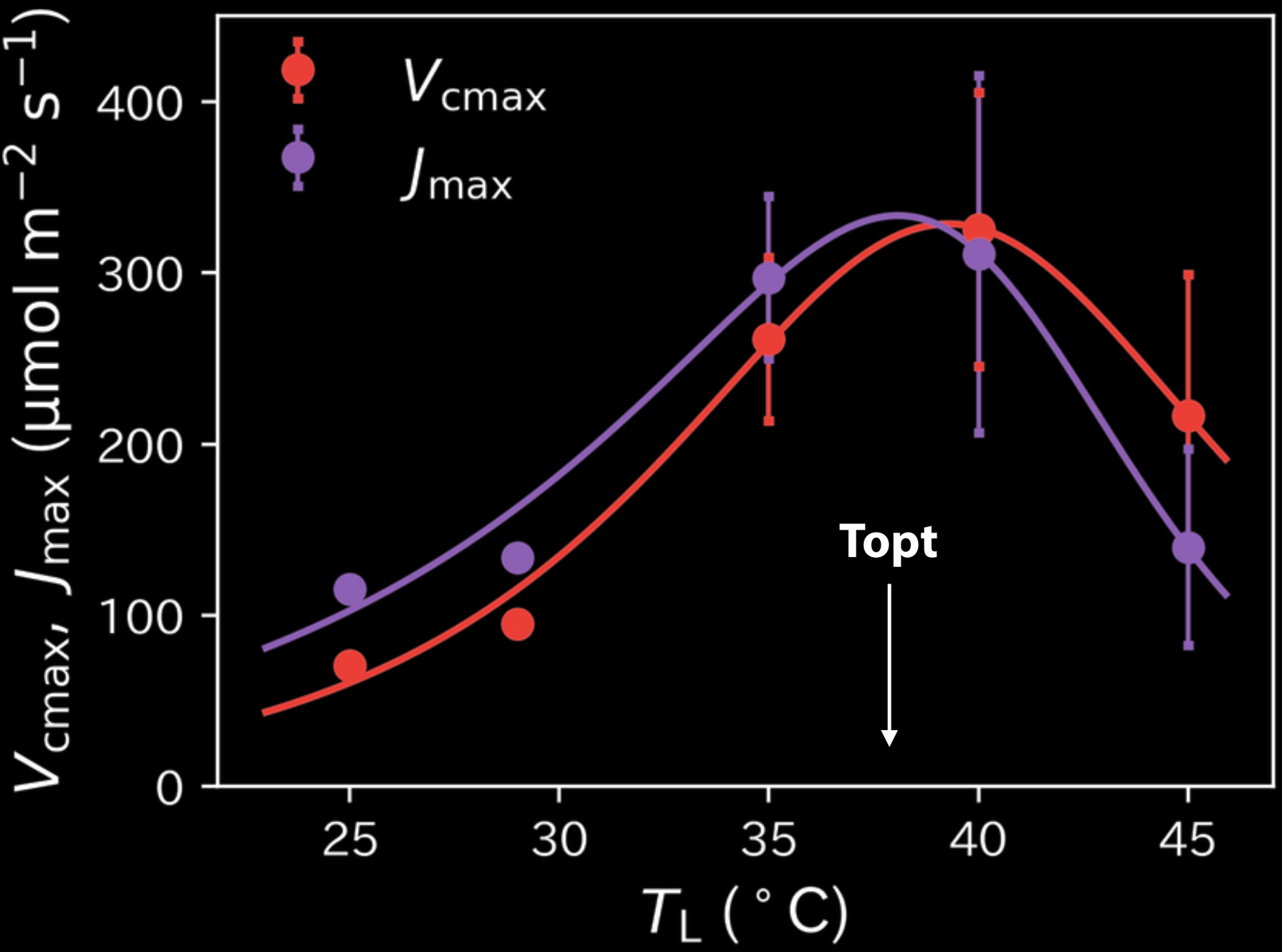




(Haverd *et al.* GCB 2020)

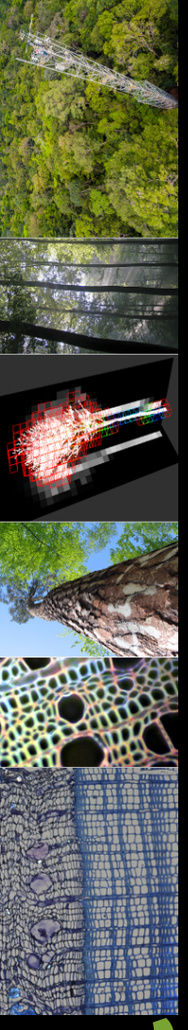
Leaves adapt to growth condition (acclim)

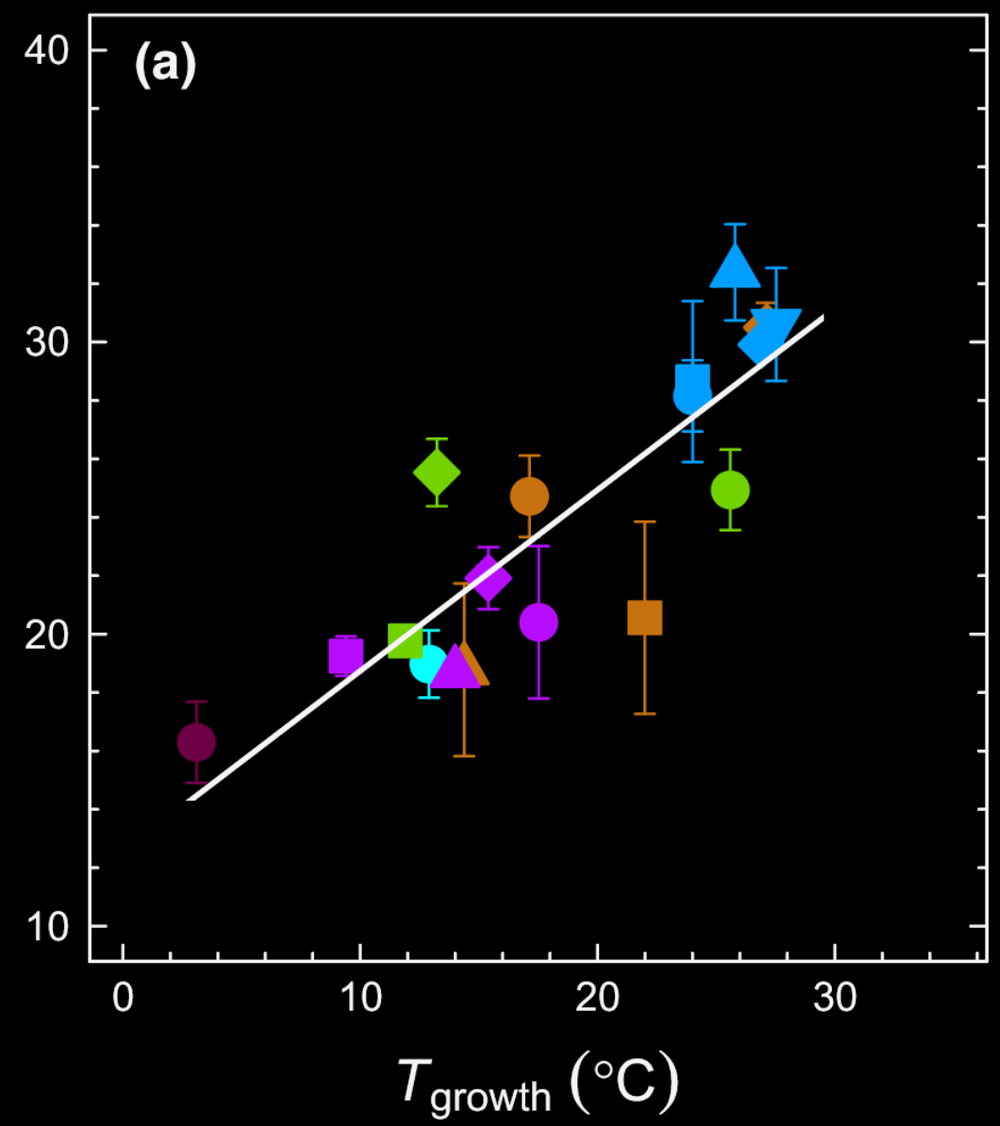




(Nomura *et al.* Photosyn Res 2023)

Leaves adapt to growth condition (acclim)



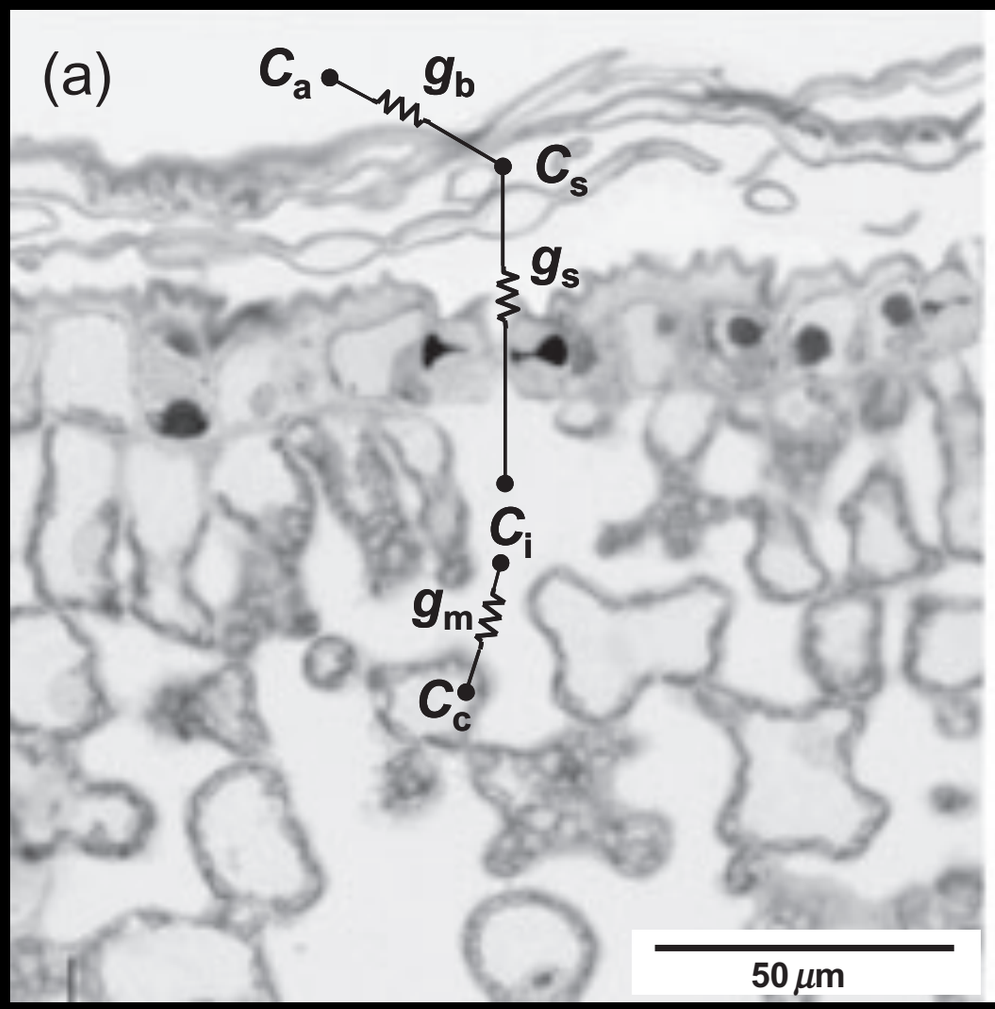


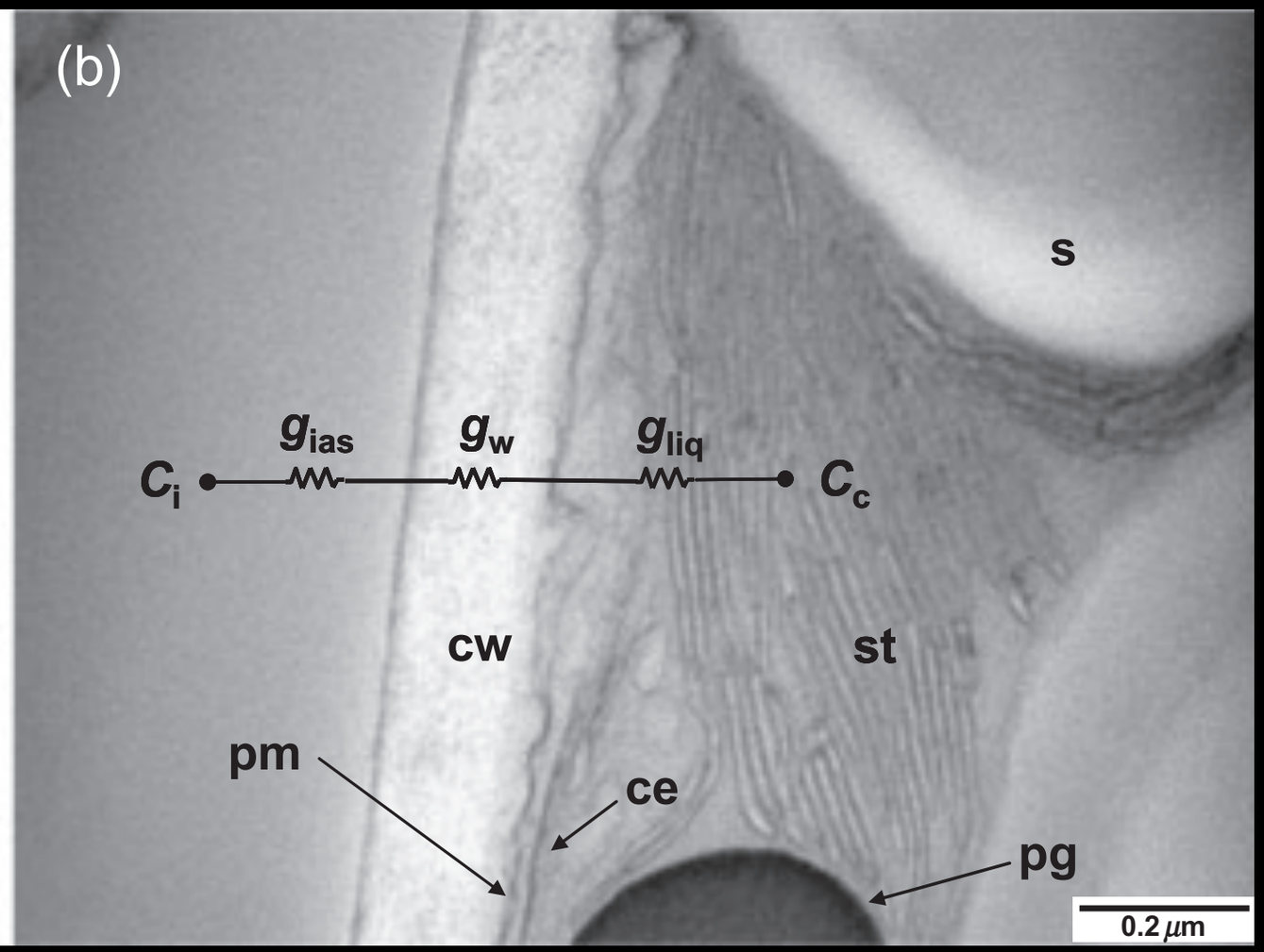
Mature plants dataset

- Mongolian oak, Japan
- Eucalyptus woodland, AU−NSW
- Semi−arid woodland, AU−WA
- Savanna eucalyptus, AU−NT
- Subalpine eucalyptus, AU−NSW
- Black spruce, USA−MN
- Norway spruce, Sweden
- Scots pine, Sweden
- Scots pine, Finland
- Loblolly pine, USA−NC
- Red pine, Japan
- Maritime pine, France
- Rainforest, Puerto Rico
- Rainforest understorey, Puerto Rico
- Rainforest, Panama
- Rainforest, Brazil
- Rainforest, AU−QLD
- Arctic tundra, USA−AK

(Kumarathunge *et al.* New Phytolo 2019)

Assimilation happens in the chloroplast, where [CO_2] is lower than in the stomata (gm)

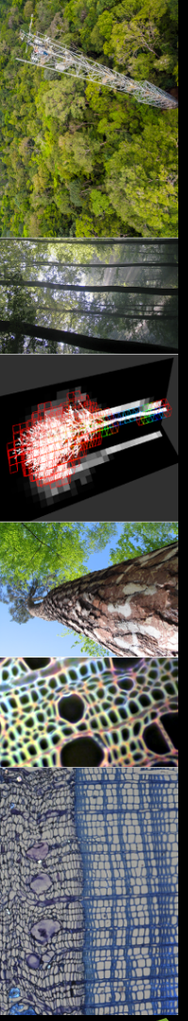




(Flexas *et al.* Plant Cell Environ 2008)

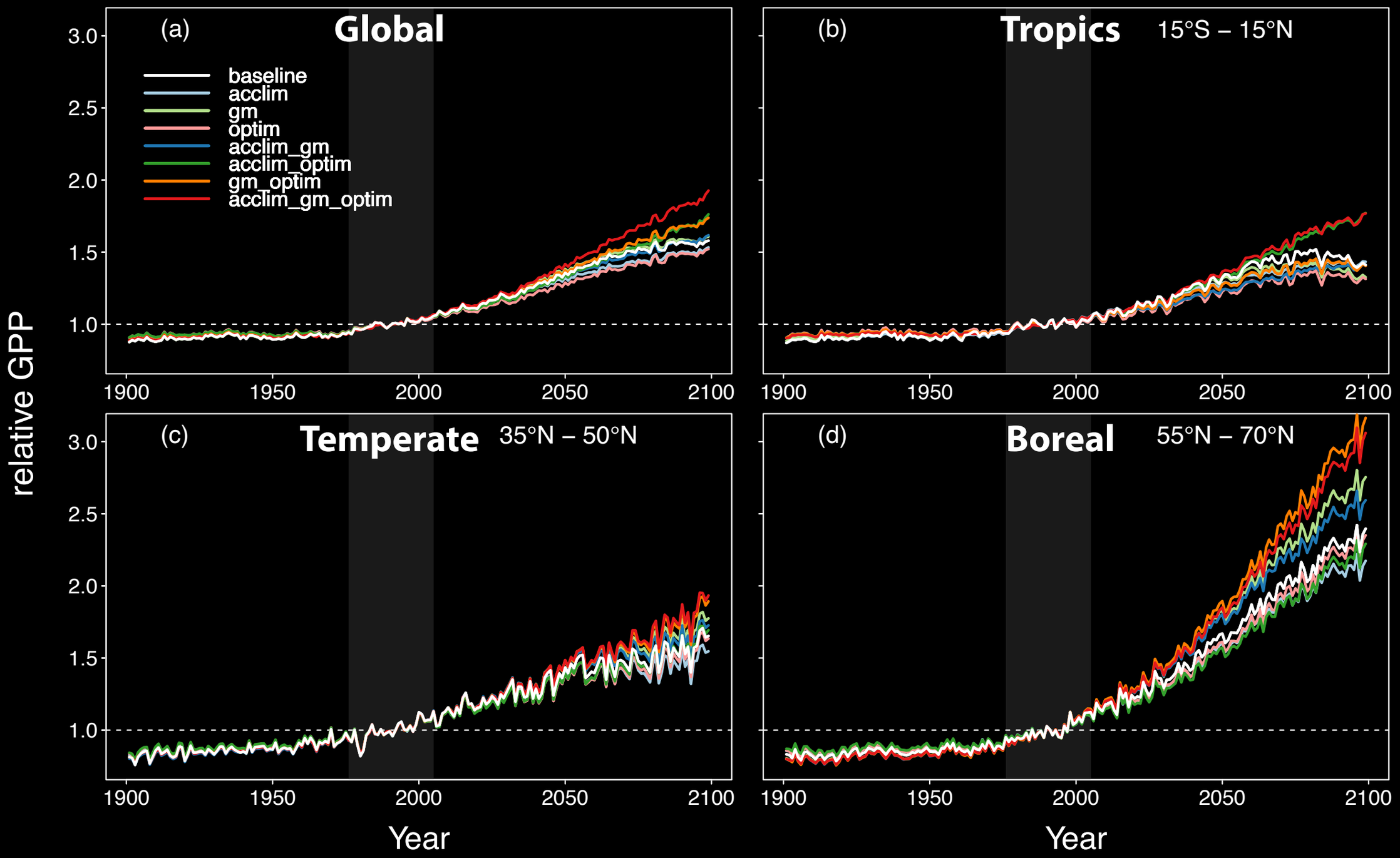
$$J_c = V_{c,max}^{C_i} \frac{C_i - \Gamma_i^*}{C_i + K_{M,i}} \xrightarrow{\text{explicit mesophyll conductance}} J_c = V_{c,max}^{C_c} \frac{C_c - \Gamma_c^*}{C_c + K_{M,c}}$$

Stronger response of GPP with more liberated model versions



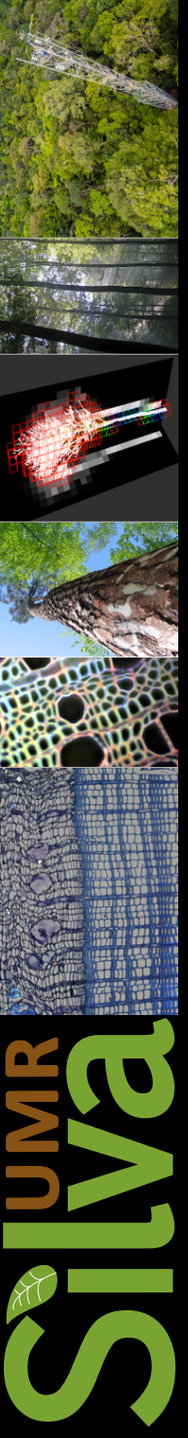
UMR Silva

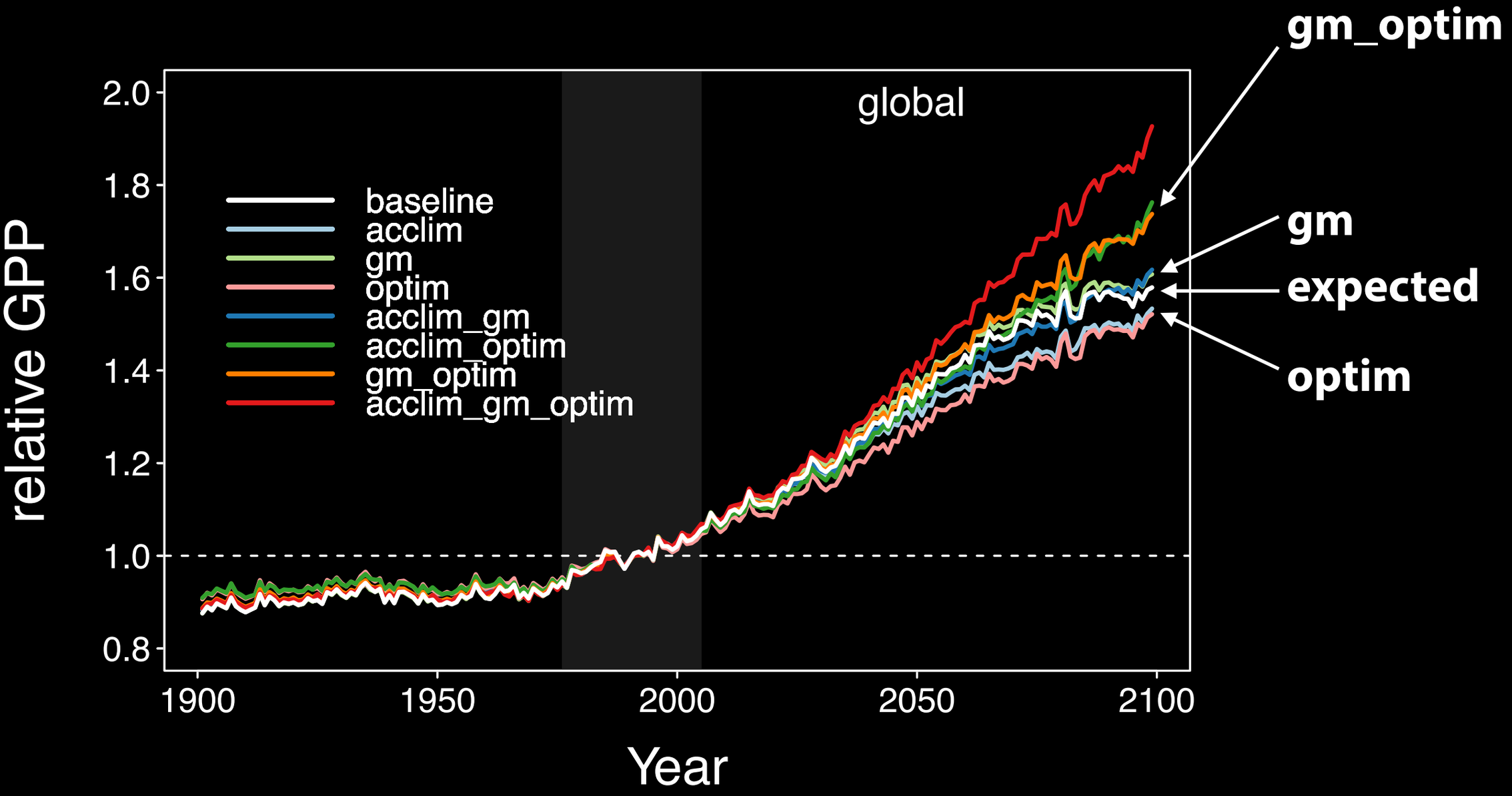
RCP8.5



(Knauer *et al.* Sci Adv 2023)

Mechanisms reinforce each other

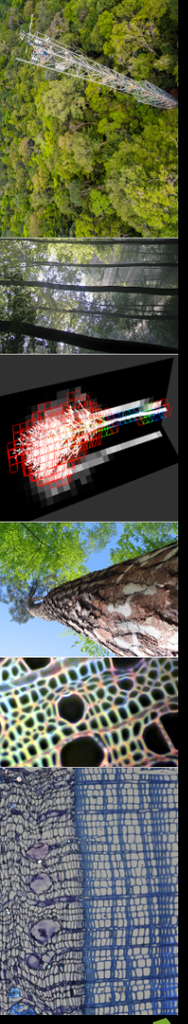


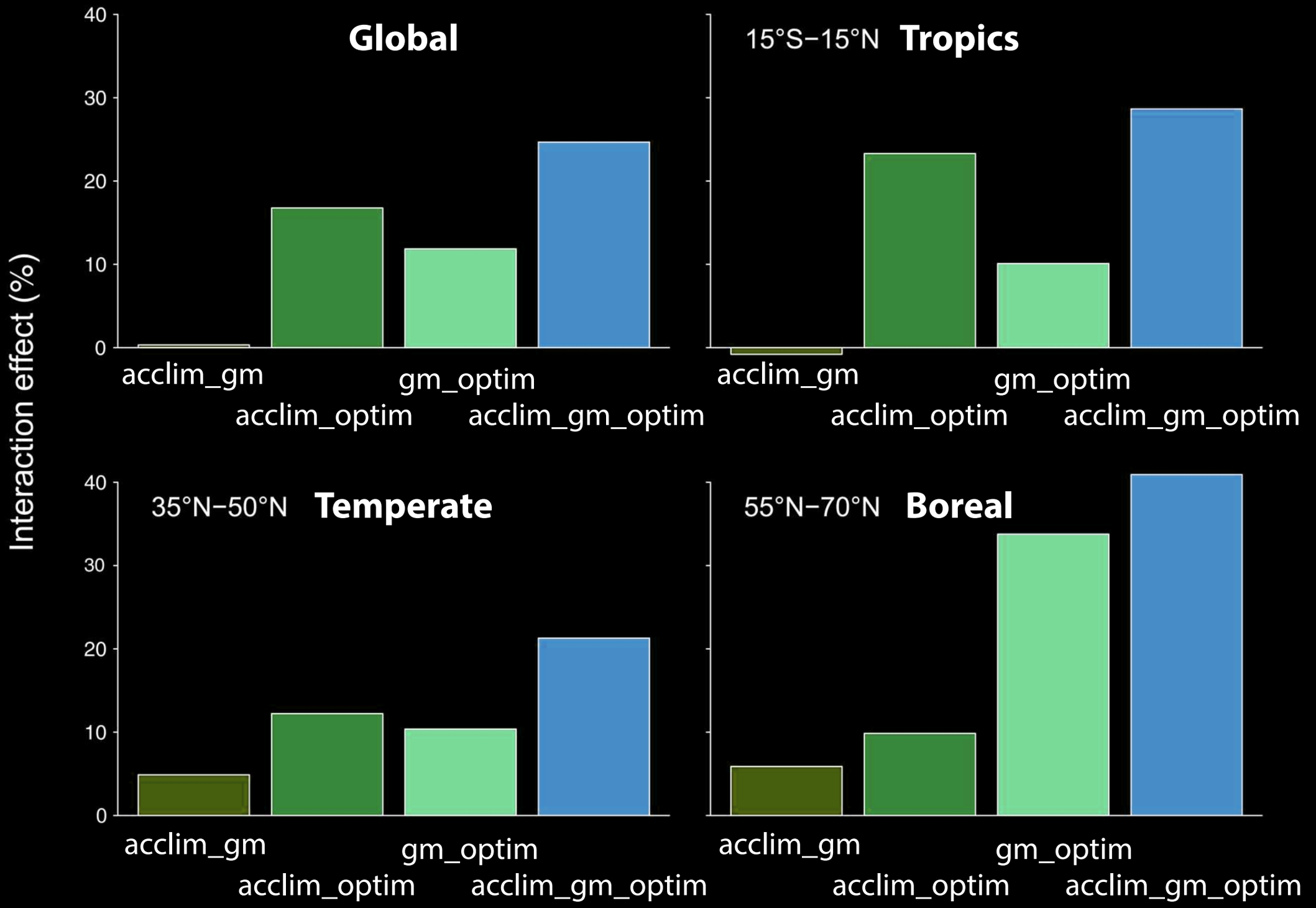


(Knauer *et al.* Sci Adv 2023)

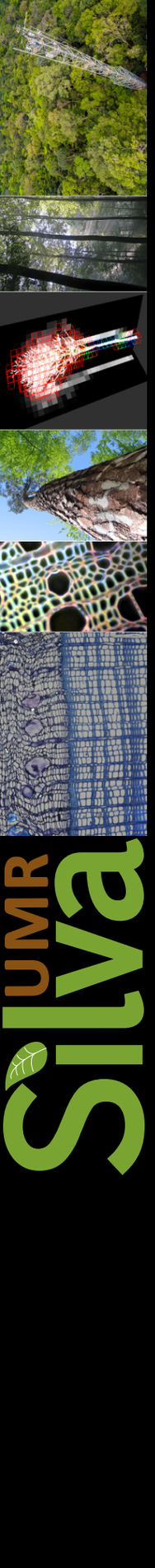
Combined effects not simply sum of individual effects but there are interactions among the processes

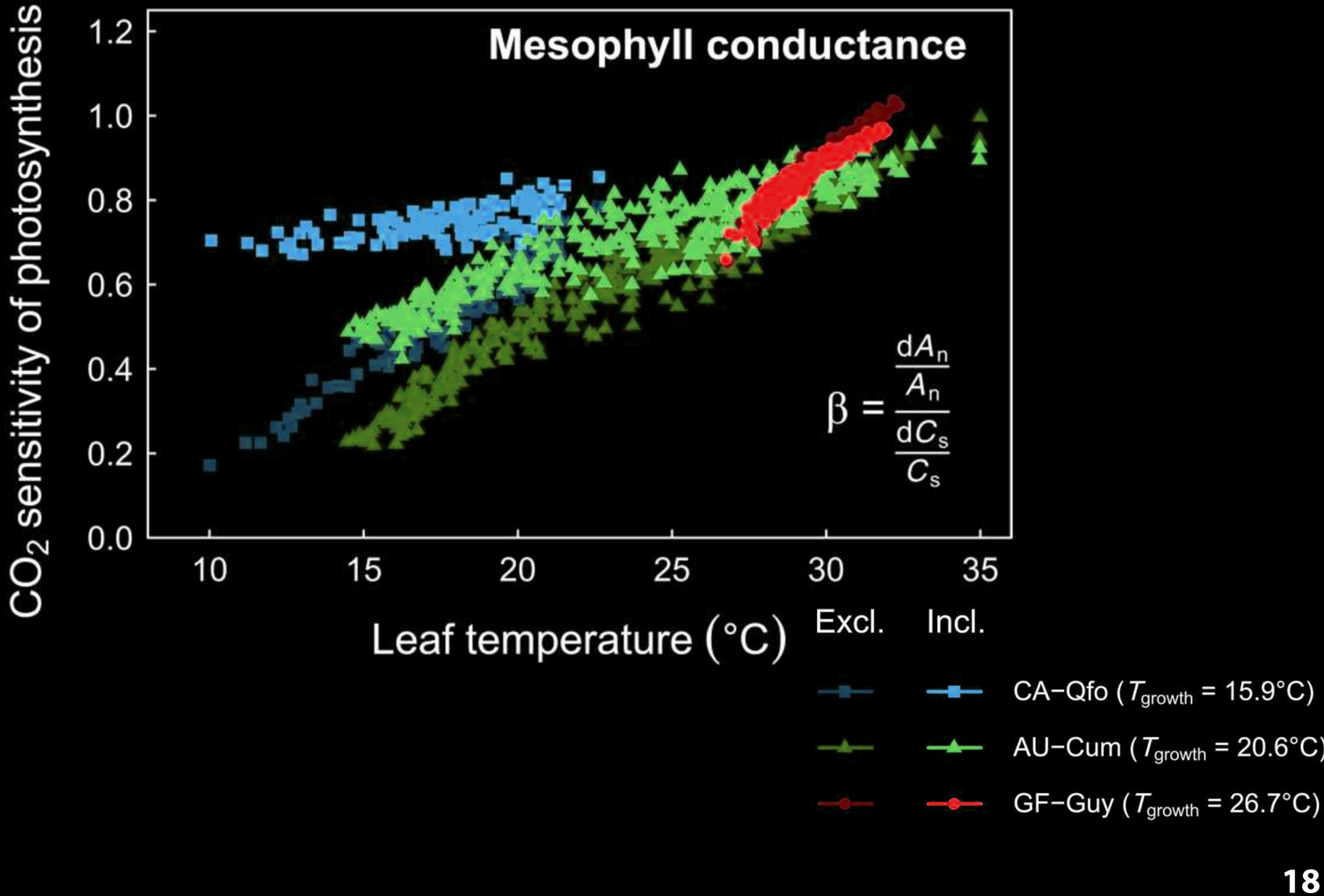
(Knauer *et al.* Sci Adv 2023)

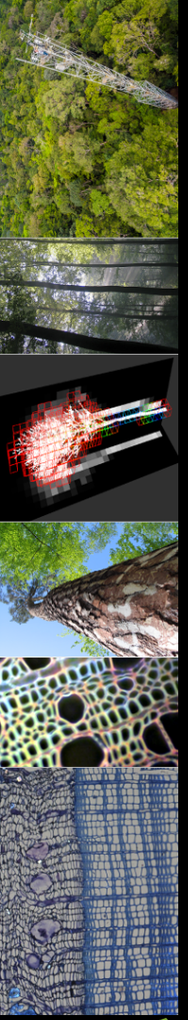




Sensitivities to temperature and [CO_2] change including or excluding individual mechanisms







Summary and Outlook

- Freeing model formulations enhances future land carbon uptake.
  ➡ up to globally 25% in 2100.
- Combined effects are not simply the sum of the individual effects but they reinforce each other.
  ➡ Temperature acclimation leads to larger sensitivity of carboxylation to temperature.
  ➡ Mesophyll conductance leads to larger sensitivity of photosynthesis to CO_2 and smaller sensitivity to temperature.
  ➡ RubisCO-limited rate is more sensitive to changes in CO_2 than electron-transport limited rate.
  Optimisation balances better both rates and leads hence to different sensitivity of photosynthesis to CO_2.

Knauer, Cuntz *et al.* (2023) Higher global gross primary productivity under future climate with more advanced representations of photosynthesis. *Science Advances* 9(46), eadh9444. doi: 10.1126/sciadv.adh9444